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Nuclear Shadowing in a Parton Recombination Model: Q^2 Variation

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ABSTRACT

Q^2 variation of the nuclear-structure-function ratio $F_2^A(x, Q^2)/F_2^D(x, Q^2)$ is investigated in a parton model with Q^2 -rescaling and parton-recombination effects. Calculated results are compared with the NMC (New Muon Collaboration) and the Fermilab-E665 experimental data. We find that our theoretical results show small Q^2 variations and that they are consistent with the data within present experimental accuracy.

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It is known that the structure functions F_2 for nuclei are different from the one for the nucleon. This is called the EMC (European Muon Collaboration) effect. The differences are found originally at medium and large Bjorken- x . In recent years, many experimental data are obtained in the small x region, which is so called the shadowing region. There are theoretical attempts to explain the EMC effect in the medium-large x region and the shadowing in the small x . However, most models investigated both regions separately and enough effort has not been made for studying the structure function in the whole x region. On the other hand, it is urgent to know nuclear parton distributions in the wide x range in order to use them for other topics in high-energy heavy-ion physics.

It is not straightforward to study a model which is valid in the wide x region. An attempt to combine the medium- x physics and the small- x one in a dynamically consistent way is made in Refs. [1, 2]. Our model is based on a parton model and is not on macroscopic nuclear physics (nuclear binding, Fermi motion, vector-meson dominance, and so on) explicitly. We simply incorporated two mechanism in our model: Q^2 rescaling and parton recombination. The rescaling has been used for explaining the EMC effect in the medium x region and the recombination for the shadowing in the small x . We calculated nuclear parton distributions by using these ideas at small Q^2 and obtained distributions are evolved by using the Altarelli-Parisi equation [1]. As a result, the ratio $[F_2^A(x)/F_2^D(x) > 1]$ in the large- x region is explained by quark-gluon recombinations. The EMC effect in the medium- x region is mainly due to the Q^2 -rescaling mechanism. The shadowing in the small- x region is due to modifications in gluon distributions. Although our theoretical results depend on input sea-quark and gluon distributions, we obtained reasonably good agreement with the EMC, the NMC (New Muon Collaboration), and the Fermilab-E665 experimental data if we choose an appropriate set of parameters. Although some Q^2 dependence is shown in Ref. [1], detailed comparison with the NMC [3] and the Fermilab-E665 [4] Q^2 -variation data is not made. The purpose of this paper is to supplement the previous publication [1] by showing the Q^2 variation explicitly.

We calculate the Q^2 rescaling and the parton recombination at small Q^2 ($\equiv Q_0^2$); then, the structure function F_2 is evolved by using the Altarelli-Parisi equation. We refer the reader to the paper in Ref. [1] for a complete account of our model and formalism. We briefly discuss our calculation in the following. We first calculate nuclear parton distributions at Q_0^2 by using the Q^2 rescaling for valence quarks. Sea-quark and gluon distributions are modified so that the momentum conservation is satisfied. Then, the obtained parton distributions are used for calculating parton-recombination effects. In this way, we get parton distributions with the Q^2 -rescaling and parton-recombination effects at Q_0^2 . These distributions are evolved by using the Altarelli-Parisi equation. According to the results in Ref. [1] (Sec. IV-C), an appropriate choice of Q_0^2 is 0.8 GeV^2 for explaining experimental data. Parameters in our model are given in Sec. IV-B of Ref. [1]. It should be noted that the Q^2 evolution in this research is calculated by using the ordinary Altarelli-Parisi equation [5], and

modifications of the Q^2 evolution due to parton recombinations [6] are not taken into account. To solve the integro-differential equation in Ref. [6] accurately is a significant research problem by itself, so we leave the full Q^2 evolution issue as our future research topic. Furthermore, the perturbative QCD would not be applicable in the small- Q^2 region, so our calculation should be considered as a naive estimate. Our Q^2 evolution results are shown in Figs. 1, 2, and 3 together with the NMC [3] and the E665 [4] data.

Figure 1 shows our results for the calcium nucleus at $x=0.0085$, 0.035 , 0.125 , and 0.55 . $x=0.0085$ and 0.035 are in the shadowing region; 0.125 is in the anti-shadowing; 0.55 is in the region of the original EMC effect. The solid [dashed] lines are the results by using the MRS-1 (Martin-Roberts-Stirling set 1) [the KMRS-B0 (Kwiecinski-Martin-Roberts-Stirling set B0)] parametrization as input distributions. Our theoretical calculations are compared with the NMC data in 1991 [3]. Used constants are the starting Q^2 ($Q_0^2=0.8$ GeV 2), the cutoff for leak-out partons ($z_0=2.0$ fm), and the rescaling parameters ($\xi_C^V=1.60$, $\xi_{Ca}^V=1.86$). It is shown in Fig. 1 that the ratio $F_2^A(x, Q^2)/F_2^D(x, Q^2)$ slightly increases with Q^2 at small x and that the ratio is almost constant at medium x . Considering the small Q^2 variations of our theoretical results and the experimental errors, we find that our results are consistent with existing experimental data.

Results in Fig. 2 are for the carbon nucleus. It shows that our results agree with the experimental data within the present experimental accuracy. Calculated Q^2 variations are rather large at $Q^2 \approx 1$ GeV 2 in the small- x region. In fact, the dotted curve ($Q^2=0.8$ GeV 2) in Fig. 7b of Ref. [1] may seem contradictory to the experimental data. However, the large Q^2 variation in Fig. 2 and the discrepancy from the data in Fig. 7b of Ref. [1] should not be taken very seriously. This is because the perturbative QCD, especially in the leading order, would not work at small Q^2 . Furthermore, as shown in Figs. 2a and 2b, the discrepancy is not so large and theoretical curves are consistent with the data if we consider the experimental accuracy.

Next, our calculations are compared with the Fermilab-E665 experimental data for the xenon nucleus [4] in Fig. 3. The experimental data are taken from the recent report in Ref. [4] and they are in the x range, $0.001 < x < 0.025$. The theoretical curves are calculated at $x = 0.01$ and 0.025 in comparison. The calculated ratio slightly increases with Q^2 . Considering that the E665 data at small Q^2 (<1 GeV 2) are obtained at small x (~ 0.002) and that the data at larger Q^2 (>3 GeV 2) are at x (~ 0.02), we find that our theoretical results agree with the E665 data reasonably well. From these comparisons in Figs. 1, 2, and 3, we conclude that the Q^2 variations calculated in our parton model are in agreement with the experimental data. However, accurate experimental data are needed for testing details of theoretical works. In the theory side, we need progress in numerical analysis of the full nuclear Q^2 evolution and in the next-to-leading-order effects [7].

Q^2 variations of the nuclear structure function ratio $F_2^A(x, Q^2)/F_2^D(x, Q^2)$ are calculated in a parton model. We incorporated two mechanisms: the Q^2 rescaling and the parton recombination, in our model in a dynamically consistent way. Calculated

results are compared with the NMC and the Fermilab-E665 experimental data. Our theoretical results show small Q^2 variation and are consistent with existing experimental data.

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Figure Captions

- Fig. 1** Q^2 variations of the ratio $F_2^{Ca}(x, Q^2)/F_2^D(x, Q^2)$ at (a) $x=0.0085$, (b) $x=0.035$, (c) $x=0.125$, and (d) $x=0.55$. Experimental data are the NMC data (1991) in Ref. [3]. The solid (dashed) curves are the calculated results by using the MRS-1 (KMRS-B0) distribution.
- Fig. 2** Q^2 variations of the ratio $F_2^C(x, Q^2)/F_2^D(x, Q^2)$. See Fig.1 for the notations.
- Fig. 3** Q^2 variations of the ratio $F_2^{Xe}(x, Q^2)/F_2^D(x, Q^2)$. The solid (dashed) curve is our result at $x=0.025$ (0.01) by using the MRS-1. Experimental data are the E665 data in the x range ($0.001 < x < 0.025$) [4].

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